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ON

THE ASTRONOMICAL CAUSES

WHICH MAY INFLUENCE

GEOLOGICAL PHÆNOMENA.

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XVII.—*On the Astronomical Causes which may influence Geological Phænomena.*

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ALTHOUGH the more immediate object of geologists in the actual state of their science is rather the collection of facts, and such an induction of conclusions from them as shall be, so far as possible, independent of theory; yet when theory confines itself to pointing out the influence of causes which we know to exist, in modifying the general condition of our globe, and enables us to estimate the extent of their action, it may be regarded as rendering a real service to science. It thus tends in some degree to diminish the complexity of the problems to be resolved, or at least to reduce them to their true difficulty, by showing what portion of them can and what cannot be accounted for on known principles, thereby narrowing the field of research, and directing the efforts of future speculators to the discovery of causes of another description.

This consideration has induced me, not without some degree of hesitation, to offer to this Society, though in a very crude and imperfect state, some views which have occurred to me of a possible explanation of a portion, at least, of that great geological phænomenon,—the difference between the actual climates now prevailing over extensive regions of the earth's surface, and perhaps over its whole extent, and those which the organic remains discovered in its strata lead us to conclude have formerly subsisted during very long periods of time. The ingenious attempts which have been lately made to account for this remarkable fact, while they show the sense of geologists of the importance of the subject, seem to indicate an impression that it is one on which we need not despair of coming to just conclusions, and that in consequence no inquiry will be considered as irrelevant which has for its object to bring into view the action of causes which demonstrably must have an influence, and respecting which the only question is its amount.

Impressed with the magnificence of that view of geological revolutions

which regards them rather as regular and necessary effects of great and general causes, than as resulting from a series of convulsions and catastrophes regulated by no laws and reducible to no fixed principles, the mind naturally turns to those immense periods with whose existence in the planetary system the astronomer is familiar; at first attracted by the analogy offered by a duration commensurate to those lapses of time which geology contemplates, and afterwards with a hope of discovering something in the fluctuations to which the orbit of our own planet is liable, which may tender a reason for at least some of the events in its geological history.

The sun and moon are the only bodies in our system whose influence can at all directly affect the condition of our globe: *both* by their effect in causing tides—the *former* by its heat. The tide produced by any luminary is, as is well known, inversely as the cube of its distance. Hence it is evident that any considerable approach of the moon to the earth would greatly increase the tides. If, for instance, the mean distance of the moon were diminished by only one tenth of its actual amount, the mean rise and fall of the tides would be increased by a full third of their present quantity, which would of course produce a great increase in their erosive action on the continents, as well as in the transporting power of the waters of the ocean over the materials of the land.

The mean distance of the moon is actually on the decrease, and has been so from the earliest ages, producing the astronomical phænomenon known by the name of the "*acceleration of the moon's mean motion*." But this decrease, which takes place with extreme slowness, has been demonstrated by Laplace to be incapable of going to any such extent as that above spoken of, and, after a period of enormous length, will be again converted into an increase, which, in like manner, will never be so great as to make any considerable change in the relations now contemplated.

The excentricity of the lunar orbit is also liable to fluctuation; and it is far from proved that, if we extend our views backwards for many millions of years, it may not formerly have been materially greater than at present, in consequence of some extensive periodical inequality, or the accumulation of many such. Now should this ever have been the case, the tides in the perigee of the moon would of course have experienced a corresponding increase. But there is no reason to believe that any possible approximation of the moon to the earth, arising from increased excentricity in her orbit, should have brought her to within two thirds of her actual perigean distance; in which supposition (purposely assumed as an extravagant one) the lunar tide would still have had less than $3\frac{1}{2}$ times its present magnitude; one which no doubt would suffice,

if at once attained, to cause great local devastations in estuaries and confined channels, but which would not account for any great diluvial phænomena, especially when it is considered that, the change taking place gradually, they would become modified in their form by insensible gradations, and thus accommodated to the altered circumstances; a remark which may be extended to the general outlines of coasts, which would be no doubt in some degree altered. It does not appear, therefore, that any admissible extent of perturbation produced by the sun's action on the lunar orbit can have materially influenced the geological state of the earth.

Let us next consider the changes arising in the orbit of the earth itself about the sun, from the disturbing action of the planets. In so doing it will be obviously unnecessary to consider the effect produced on the solar tides, to which the above reasoning applies much more forcibly than in the case of the lunar. It is therefore only the variations in the supply of light and heat received from the sun that we have now to consider.

Geometers having demonstrated the absolute invariability of the *mean* distance of the earth from the sun, it would seem to follow that the mean annual supply of light and heat derived from that luminary would be alike invariable: but a closer consideration of the subject will show that this would not be a legitimate conclusion; but that, on the contrary, the *mean* amount of solar radiation is dependent on the excentricity of the orbit, and therefore liable to variation. Without going at present into any geometrical investigations, it will be sufficient for the purpose here to state it as a theorem, of which any one may easily satisfy himself by no very abstruse geometrical reasoning, that "*the excentricity of the orbit varying, the* total *quantity of heat received by the earth from the sun in one revolution, is inversely proportional to the* minor *axis of the orbit.*" Now since the major axis is, as above observed, invariable, and therefore, of course, the absolute length of the year, it will follow that, the *mean annual* average of heat will also be in the same inverse ratio of the *minor* axis; and thus we see that the very circumstance which, on a cursory view, we should have regarded as demonstrative of the constancy of our supply of solar heat, forms an essential link in the chain of strict reasoning by which its variability is proved.

The excentricity of the earth's orbit is actually diminishing, and has been so for ages beyond the records of history. In consequence the ellipse is in a state of approach to a circle; and its minor axis being therefore on the increase, the annual average of solar radiation is actually on the *decrease*.

So far this is in accordance with the testimony of geological evidence, which indicates a general refrigeration of climate; but when we come to consider

the amount of diminution which the excentricity must be supposed to have undergone, to render an account of the variation which has taken place, we have to consider that, in the first place, a great diminution of the excentricity is required to produce any sensible increase of the minor axis. This is a purely geometrical conclusion, and is best shown by the following table.

Excentricity.	Minor axis.	Reciprocal, or Ratio of Heat received.
0.00	1.000	1.000
0.05	0.999	1.002
0.10	0.995	1.005
0.15	0.989	1.011
0.20	0.980	1.021
0.25	0.968	1.032
0.30	0.954	1.048

By this it appears that a variation of the excentricity of the orbit, from the circular form to that of an ellipse having an excentricity of one fourth of the major axis, would produce only a variation of 3 per cent. on the *mean* annual amount of solar radiation ; and this variation takes in the whole range of the planetary excentricities, from that of Pallas and Juno downwards.

I am not aware that the limit of increase of the excentricity of the earth's orbit has ever been determined. That it has a limit has been satisfactorily proved ; but the celebrated theorem of Laplace, which is usually cited as demonstrating that none of the planetary orbits can ever deviate materially from the circular form*, leads to no such conclusion, except in the case of the great preponderant planets Jupiter and Saturn ; while, for anything that theorem proves to the contrary, the orbit of the earth may become elliptic to any amount.

In the absence of calculations which, though practicable, have, I believe, never been made, and would be no slight undertaking, we may assume that excentricities which exist in the orbits of planets both interior and exterior to that of the earth, may *possibly* have been attained, and may be attained again, by that of the earth itself. It is clear that, such excentricities *existing*, they cannot be incompatible with the stability of the system generally ; and that therefore the question of the possibility of such an amount in the particular case of the earth's orbit, will depend on the particular data belonging to that case, and can only be determined by executing the calculations alluded to, having regard to the simultaneous effects of at least the four most influential planets Venus, Mars, Jupiter, and Saturn, *not only on the orbit of the earth, but on those of each other*. The principles of this calcula-

* *Mécanique Céléste*, Book II. No. 57.—Equation (u).

tion are detailed in the article of Laplace's work cited. But before entering on a work of so much labour, it is quite necessary to inquire what prospect of advantage there is to induce any one to undertake it.

Now it certainly at first sight seems clear, that a variation of 3 per cent. only, in the mean annual amount of solar radiation, and that arising from an extreme supposition, does *not* hold out such a prospect. Yet it might be argued, that the effect of the sun's heat is to maintain the temperature of the earth's surface at its actual mean height, not above the zero of Fahrenheit's or any other thermometer, but above the temperature of the celestial spaces out of the reach of the sun's influence; and what that temperature is, may be a matter of much discussion. M. Fourrier has considered it as demonstrated that it is not greatly inferior to that of the polar regions of our own globe; but the grounds of this decision appear to me open to considerable objection*. If those regions be really void of matter, their temperature can only arise, according to M. Fourrier's own view of the subject, from the radiation of the stars. It ought therefore to be as much inferior to that due to solar radiation, as the light of a starlight night is to that of the brightest noon day; in other words, it should be very nearly a total privation of heat†,—almost the *absolute zero,* respecting which so much difference of opinion exists; some placing it at 1000, some at 5000 degrees of Fahrenheit below the freezing point, and some still lower, in which case a single unit per cent. in the mean annual amount of radiation would suffice to produce a change of climate fully commensurate to the demands of geologists.

Without attempting, however, to enter further into the perplexing difficulties in which this point is involved, which are far greater than appear on a cursory view, let us next consider, not the *mean* but the *extreme* effects which a variation in the excentricity of the earth's orbit may be expected to produce in the summer and winter climates in particular regions of its surface, and under the influence of circumstances favouring a difference of effect. And here, if I mistake not, it will appear, that an amount of variation, which we need not hesitate to admit (at least provisionally) as a possible one, may be productive of considerable diversity of climate, and may operate during

* *Mém. de l'Acad. Royale des Sciences*, 1827, tom. vii. p. 598.

† The proportion of the light of the sun to that of the moon has been estimated by Bouguer as 300,000 to 1. If we regard the illumination of full moonlight as only 100 times greater than that of a bright starlight night, which is a very moderate supposition, we shall have a ratio of 30,000,000 to 1 for the illuminating power of the sun compared to that of all the stars in our hemisphere, and consequently 15,000,000 to 1 for the ratio of the heating effect of the sun to that of all the stars in both hemispheres.

great periods of time either to mitigate or to exaggerate the difference of winter and summer temperatures, so as to produce alternately in the same latitude of either hemisphere a perpetual spring, or the extreme vicissitudes of a burning summer and a rigorous winter.

To show this, let us take at once the extreme case of an orbit as excentric as that of Juno or Pallas, in which the greatest and least distances of the sun are to each other as 5 to 3, and consequently the radiations at those distances as 25 to 9, or very nearly as 3 to 1. To conceive what would be the *extreme* effects of this great variation of the heat received at different periods of the year, let us first imagine in our latitude, the place of the perigee of the sun to coincide with the summer solstice. In that case the difference between the summer and winter temperature would be exaggerated in the same degree as if three suns were placed side by side in the heavens in the former season, and only one in the latter, which would produce a climate perfectly intolerable. On the other hand, were the perigee situated in the winter solstice, our three suns would combine to warm us in the winter, and would afford such an excess of winter radiation as would probably more than counteract the effect of short days and oblique sunshine, and throw the summer season into the winter months.

The actual diminution of the excentricity is so slow, that the transition from a state of the orbit, such as we have assumed, to the present nearly circular figure, would occupy upwards of 600,000 years, supposing it uniformly changeable;—this of course would not be the case: when near the maximum, however, it would vary slower still, so that at that point, it is evident, a period of 10,000 years would elapse without any perceptible change in the state of the data of the case we are considering.

Now this, adopting the very ingenious idea of Mr. Lyell*, would suffice, by reason of the combined effect of the precession of the equinoxes and the motion of the apsides of the orbit itself, to transfer the perigee from the sum-

* Principles of Geology, p. 110.—Mr. Lyell, however, in stating the actual excess of eight days in the duration of the sun's presence in the northern hemisphere over that in the southern, as productive of an excess of light and heat annually received by the one over the other hemisphere, appears to have misconceived the effect of elliptic motion in the passage here cited; since it is demonstrable that, whatever be the ellipticity of the earth's orbit, the two hemispheres must receive equal absolute quantities of light and heat per annum, the proximity of the sun in perigee exactly compensating the effect of its swifter motion. This follows from a very simple theorem, which may be thus stated: "The amount of heat received by the earth from the sun while describing any part of its orbit, is proportional to the angle described round the sun's centre." So that if the orbit be divided into two portions by a line drawn *in any direction* through the sun's centre, the heats received in describing the two unequal segments of the ellipse so produced will be equal.

mer to the winter solstice, and thus to produce a transition from the one to the other species of climate, in a period sufficiently great to give room for a material change in the botanical character of a country.

The supposition above made is an extreme, but it is not demonstrated to be an impossible one; and should even an approach to such a state of things be possible, the same consequences, in a mitigated degree, would follow. But if on executing the calculations it should appear that the limits of the excentricity of the earth's orbit are really narrow; and if, on a full discussion of the very difficult and delicate point of the actual effect of solar radiation, it should appear that the mean as well as extreme temperature of our climates would *not* be materially affected,—it will be at least satisfactory to *know* that the causes of the phænomena in question are to be sought elsewhere than in the relations of our planet to the system to which it belongs; since there does not appear to exist any other conceivable connection between those relations and the facts of geology than those we have enumerated, the obliquity of the ecliptic being, as we know, confined within too narrow limits for its variation to have any sensible influence.

J. F. W. Herschel.